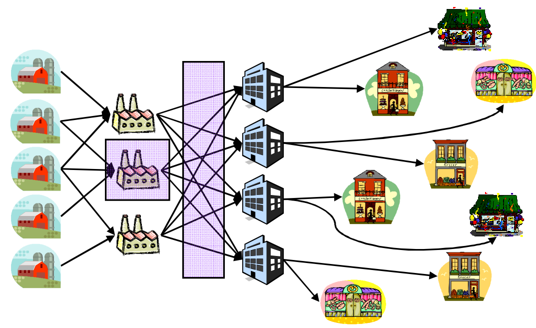
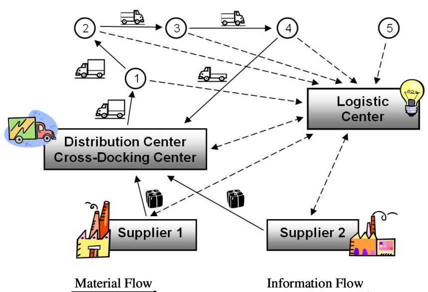
SUPPLY CHAIN MANAGEMENT

Supply chain



Another model of a supply chain



Introduction

- **Main objective:** *to produce and deliver finished products to end costumers in the most effective and timely manner.*

Levels and horizons

Level	*Horizon*	*Types of decisions*
Strategic	1 – 5 years	Facility location, new products
Tactical	2 – 6 months	Sourcing, distribution, orders assigned to plants
Operational	7 to 21 days	Production & transportation scheduling details

Planning vs. Scheduling

	Planning	**Scheduling**
Horizon	Multiple stages, medium term	One stage/facility, short term
Information	Aggregate	Detailed
Objective	Profit	Time (e.g,. tardiness, makespan)

Hierarchical decomposition

- Planning solves higher level problems based on aggregate data
- The planning decisions are then used as constraints (e.g., due dates) for the scheduling
  - May be multiple independent scheduling problems
  - Planning is decoupled to scheduling problems

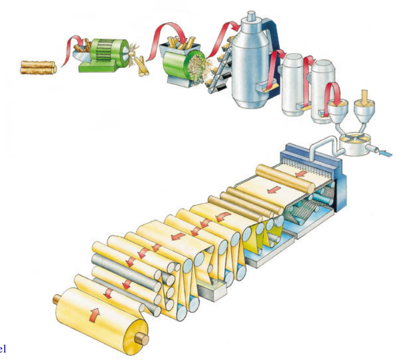
Supply chain settings and configurations

- **Continuous manufacturing industries**
  - Main inventory/products are finely divisible
  - Examples: steel, shampoo, paper
- **Discrete manufacturing industries**
  - Main inventory/products are individually countable
  - Examples: cars, computers, consumer electronics
- ➢ Scheduling problems are different.

Continuous: (I-a) main processing

- Raw materials are transformed to intermediate products
- Machines have high start-up/shutdown costs and
- High changeover costs
- Often fixed batch sizes
- Usually run 24/7

Example: paper industry



Continuous: (I-b) finishing

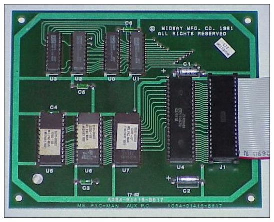
- Products of main processes are "specialized"
  - Cut, bent, extruded, painted, printed, …
- Often these are commodities
  - Many clients
  - Mix of make-to-stock and make-to-order
- Due dates, sequence dependent changeovers, and inventory management are important

Discrete: (II-a) primary conversion

- Similar to finishing in continuous
  - Stamping, bending, cutting
- Process is generally relatively simple
- Output is often a part
  - Car body part, computer case, …
- Schedule is often integrated with downstream processes

Discrete: (II-b) main production

- Many different operations of many tools
  - 100 step process for semiconductors
- Machines are very expensive
- Often organized as a job shop
- Each order has its own route, quantity, due date
- Sequence dependent changeovers



Discrete: (II-c) assembly

- Put different parts together
- Typically does not alter the shape or form of any individual part
- Machines are cheap but material handling is important; can include robotic equipment.
- Assembly lines
  - cars or consumer electronics
- Due dates, changeovers, sequencing, …

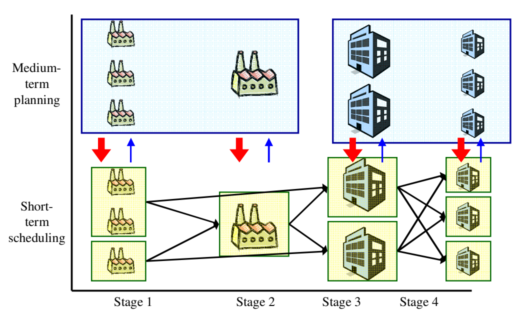
Operating characteristics

Sector	*Process*	*Time horizon*	*Clock speed*	*Differentiation*
Continuous: Main	Planning	Long-medium	Low	Very low
Continuous: Finishing	Planning/ scheduling	Medium-short	Medium/ High	Medium/low
Discrete: Conversion	Planning/ scheduling	Medium-short	Medium	Very low
Discrete: Main	Planning/ scheduling	Medium-short	Medium	Medium/low
Discrete: Assembly	Scheduling	Short	High	High

Model types and solution techniques

Sector	*Models*	*Solution Technique*
Continuous: Main	Lot-sizing, cyclic scheduling	Mixed Integer Programming
Continuous: Finishing	Single machine, parallel machine	Batch scheduling, inventory rules and dispatch rules
Discrete: Conversion	Single machine, parallel machine	Batch scheduling, dispatching rules, CP
Discrete: Main	Flow shop, job shop	IP, shifting bottleneck, dispatching, CP, LS
Discrete: Assembly	Assembly line	Grouping and Spacing, (meta)-heuristics, make-to-order/JIT, CP, LS

Planning and scheduling



Medium-term planning

- Minimize total cost over all stages
- Costs:
  - Production costs
  - Holding or storage costs
  - Transportation costs
  - Tardiness costs
  - Non-delivery costs
  - Costs for increasing resource capacities (e.g. third shifts)
  - Costs for increasing storage capacities

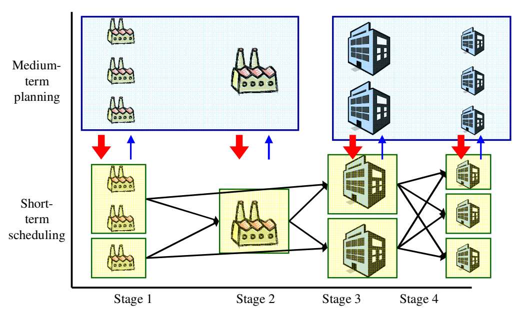
Medium-term aggregation

- ❑ Time abstraction
  - 1 unit = 1 week or 1 month (not 1 day)
- ❑ Product abstraction
  - Work at product “family” level
  - ❖Example: Tuborg beer, not 6-pack, 12, 24, keg, …
- ❑ Cost/job/capacity abstraction
  - Average processing times
  - Sequence dependencies ignored
  - Factory treated as a single resource

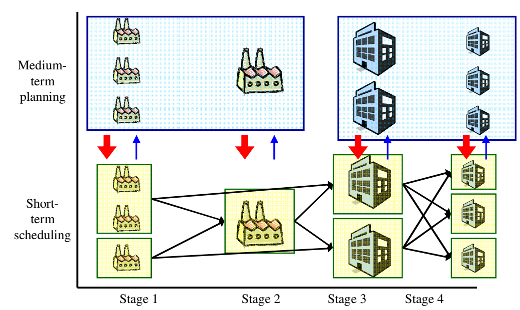
Medium-term planning results

- ❑ Daily or weekly
  - Demand for product families at each facility
  - Inventory levels
  - Transportation requirements
- ❑ **No detailed scheduling has been done!**

Medium-term constrains short-term



Medium-term decouples short-term



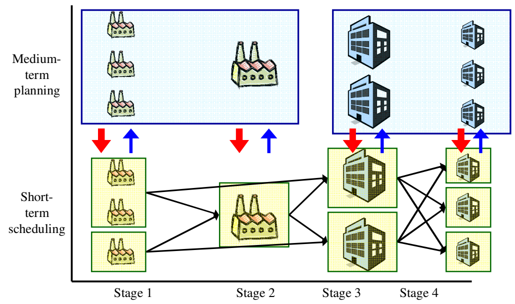
Short-term scheduling

- ❑ **Uses more precise data**:
- ❑ Time in minutes or seconds
- ❑ Horizon ≈ week, 2 weeks
- ❑ Facilities (jobs and resources) are detailed
- ❑ Set-up time/cost are taken into account
- ❑ Product demand is precisely defined
  - Demand for each product is represented

Possible problems

- ❑ **Short term schedule solution may not exist!**
  - **Why?**
- ❑ May require feedback of information to the medium-term and a run of the software application
- ❑ See SAP slides!
  - Carlsberg takes 10-12 hours in SAP for a medium-term solve …

Feedback mechanism needed

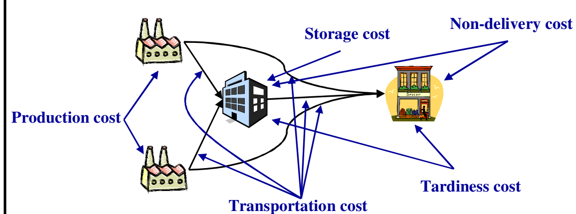


A medium term planning model

Assumptions:

- 4 week horizon
- 2 product families
- 3 stages: 2 factories, 1 distribution center (DC), 1 customer
- Factories work 24/7 = 168 hours/week

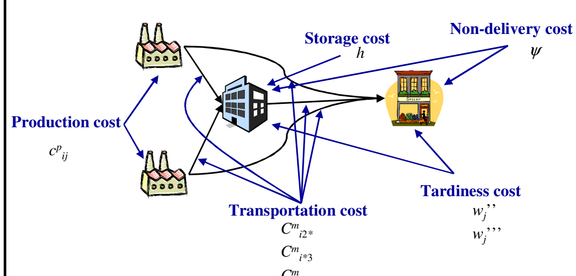
Medium-term planning costs



Costs

Production	c^p_{ij}	Cost to produce one unit of family j at factory i
Storage	h	Weekly holding cost for one unit of any type at DC
Transportation	C^m_{i2*}	Cost of moving one unit of any type from factory i to DC
	C^m_{i*3}	Cost of moving one unit of any type from factory i to the customer
	C^m_{*23}	Cost of moving one unit of any type from DC to the customer
Tardiness	w_j''	Cost per unit per week for an order of family i delivered late to DC
	w_j'''	Cost per unit per week for an order of family i delivered late to customer
Non-delivery	ψ	Penalty cost for never delivering one unit of any product

Medium-term planning costs



IP objective

x_{ijt} = # units of family j produced at factory i in week t

minimize

$$\boxed{\sum_{t=1}^{4}\sum_{j=1}^{2}\sum_{i=1}^{2} c^p_{ij} x_{ijt}} + \sum_{t=1}^{4}\sum_{j=1}^{2} h q_{2jt} +$$

$$\sum_{t=1}^{4}\sum_{j=1}^{2}\sum_{i=1}^{2} c^m_{i2*} y_{i2jt} + \sum_{t=1}^{4}\sum_{j=1}^{2}\sum_{i=1}^{2} c^m_{i*3} y_{i3jt} + \sum_{t=1}^{4}\sum_{j=1}^{2} c^m_{*23} z_{jt} +$$

$$\sum_{t=1}^{3}\sum_{j=1}^{2} w_j'' v_{2jt} + \sum_{t=1}^{3}\sum_{j=1}^{2} w_j''' v_{3jt} +$$

$$\sum_{j=1}^{2} \psi v_{2j4} + \sum_{j=1}^{2} \psi v_{3j4}$$

Production Costs

IP objective

minimize

q_{2jt} = # units of family *j* in storage at DC at end of week *t*

$$\sum_{t=1}^{4}\sum_{j=1}^{2}\sum_{i=1}^{2} c^{p}{}_{ij}x_{ijt} + \boxed{\sum_{t=1}^{4}\sum_{j=1}^{2} hq_{2jt}} +$$
$$\sum_{t=1}^{4}\sum_{j=1}^{2}\sum_{i=1}^{2} c^{m}{}_{i2*}y_{i2jt} + \sum_{t=1}^{4}\sum_{j=1}^{2}\sum_{i=1}^{2} c^{m}{}_{i*3}y_{i3jt} + \sum_{t=1}^{4}\sum_{j=1}^{2} c^{m}{}_{*23}z_{jt} +$$
$$\sum_{t=1}^{3}\sum_{j=1}^{2} w''_{j}v_{2jt} + \sum_{t=1}^{3}\sum_{j=1}^{2} w'''_{j}v_{3jt} +$$
$$\sum_{j=1}^{2}\psi v_{2j4} + \sum_{j=1}^{2}\psi v_{3j4}$$

Storage Costs

IP objective

minimize

Transportation Costs

$$\sum_{t=1}^{4}\sum_{j=1}^{2}\sum_{i=1}^{2} c^{p}{}_{ij}x_{ijt} + \sum_{t=1}^{4}\sum_{j=1}^{2} hq_{2jt} +$$
$$\boxed{\sum_{t=1}^{4}\sum_{j=1}^{2}\sum_{i=1}^{2} c^{m}{}_{i2*}y_{i2jt} + \sum_{t=1}^{4}\sum_{j=1}^{2}\sum_{i=1}^{2} c^{m}{}_{i*3}y_{i3jt} + \sum_{t=1}^{4}\sum_{j=1}^{2} c^{m}{}_{*23}z_{jt} +}$$
$$\sum_{t=1}^{3}\sum_{j=1}^{2} w''_{j}v_{2jt} + \sum_{t=1}^{3}\sum_{j=1}^{2} w'''_{j}v_{3jt} +$$
$$\sum_{j=1}^{2}\psi v_{2j4} + \sum_{j=1}^{2}\psi v_{3j4}$$

y_{i2jt}	# of units of family *j* transported from factory *i* to DC in week *t*
y_{i3jt}	# of units of family *j* transported from factory *i* to customer in week *t*
z_{jt}	# of units of family *j* transported from DC to customer in week *t*

IP objective

minimize

v_{2jt} = # units of family *j* tardy at DC at end of week *t*

v_{3jt} = # units of family j tardy at customer at end of week *t*

$$\sum_{t=1}^{4}\sum_{j=1}^{2}\sum_{i=1}^{2} c^{p}{}_{ij}x_{ijt} + \sum_{t=1}^{4}\sum_{j=1}^{2} hq_{2jt} +$$
$$\sum_{t=1}^{4}\sum_{j=1}^{2}\sum_{i=1}^{2} c^{m}{}_{i2*}y_{i2jt} + \sum_{t=1}^{4}\sum_{j=1}^{2}\sum_{i=1}^{2} c^{m}{}_{i*3}y_{i3jt} + \sum_{t=1}^{4}\sum_{j=1}^{2} c^{m}{}_{*23}z_{jt} +$$
$$\boxed{\sum_{t=1}^{3}\sum_{j=1}^{2} w''_{j}v_{2jt} + \sum_{t=1}^{3}\sum_{j=1}^{2} w'''_{j}v_{3jt}} +$$
$$\sum_{j=1}^{2}\psi v_{2j4} + \sum_{j=1}^{2}\psi v_{3j4}$$

Tardiness Costs

IP objective

minimize

v_{2j4} = # units of family *j* not delivered to DC at end of horizon

v_{3j4} = # units of family *j* not delivered to customer at end of horizon

$$\sum_{t=1}^{4}\sum_{j=1}^{2}\sum_{i=1}^{2} c^{p}{}_{ij}x_{ijt} + \sum_{t=1}^{4}\sum_{j=1}^{2} hq_{2jt} +$$
$$\sum_{t=1}^{4}\sum_{j=1}^{2}\sum_{i=1}^{2} c^{m}{}_{i2*}y_{i2jt} + \sum_{t=1}^{4}\sum_{j=1}^{2}\sum_{i=1}^{2} c^{m}{}_{i*3}y_{i3jt} + \sum_{t=1}^{4}\sum_{j=1}^{2} c^{m}{}_{*23}z_{jt} +$$
$$\sum_{t=1}^{3}\sum_{j=1}^{2} w''_{j}v_{2jt} + \sum_{t=1}^{3}\sum_{j=1}^{2} w'''_{j}v_{3jt} +$$
$$\boxed{\sum_{j=1}^{2}\psi v_{2j4} + \sum_{j=1}^{2}\psi v_{3j4}}$$

Non-delivery Costs

Production constraints

$$\sum_{j=1}^{2}\hat{p}_{ij}x_{ijt} \le 168, \quad t = 1,\ldots,4; i = 1,2$$

Total weekly hours

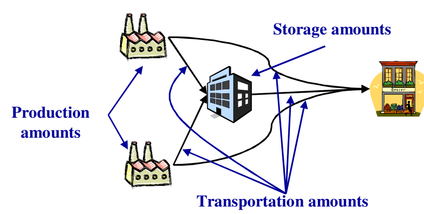
Estimate processing time for 1 unit of family *j* at factory *i*

units of family *j* produced at factory *i* in week *t*

Plus storage constraints, transportation constraints, tardiness constraints, and non-delivery constraints (see Pinedo p. 189-190)

Medium-term Planning

- computes:



Short term scheduling

- Production schedule at factories
  - what products on what machines and when?
- Transportation schedule between factories, DC, and customers
  - what products on what trucks and when?

Short term scheduling

- For each week the number of items of each family that need to be produced is known (from x_{ijt})
- However, that number is based on an estimate of the processing time required:
- ➢ In reality each product has a process plan including release date, due date, quantity, and setups.

"Normal" scheduling problem?

- Like in manufacturing or service problems?
- But … we have a **modeling problem:**
- ➢ **How much of the "real world" is represented?**
- Model can be single machine, parallel machines job shop or flexible flow shop depending on the focus
  - can be only on the bottleneck machine(s)

Short term model with parallel machines

- minimize

$$\alpha_1 \sum w_j T_j + \alpha_2 \sum I_{ijk} s_{ijk}$$

Weighting parameters

Setup cost if job k follows job j on machine i

- **Very hard problem!**

Single machine

- Schedule really depends on a single bottleneck machine
  - if the bottleneck schedule is fixed, everything else is relatively easy
- May be a much easier problem in practice.

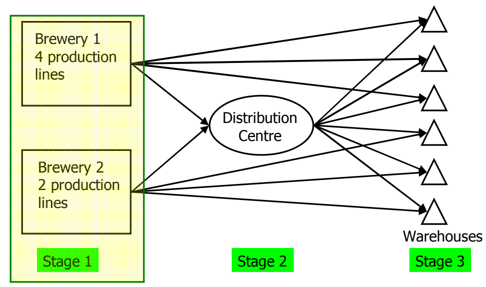
Modeling problem

- It is an open research question of how one take a real factory (or call centre) and create a "model" of it with optimization tools
  - What's the best level of detail?
  - What can you ignore?
- Research developed at the CIS/IDMEC:
  - Objective function formulated in fuzzy terms
  - Use of meta-heuristics to solve optimization problems
  - Distributed optimization paradigm

Example: Carlsberg Denmark

- Sells many different brands of beer
- Sells many different “formats”
  - bottles, cans, kegs
  - 6-pack, 12, 24

Carlsberg supply chain



Stage 1 scheduling

- 3 production steps on each line
  - brewing (and fermentation)
  - filtering
  - filling – bottling/packaging
- All are resource constrained but filling is usually the bottleneck
  - Filling operation has different costs and processing times

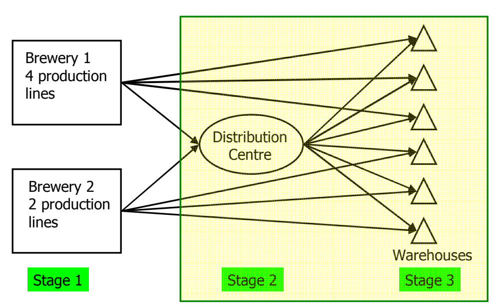
Stage 1 scheduling

- All orders have fixed “lot size”
- Products are divided into A, B, C categories
  - A – high runners – a lot of demand
  - C – specialty beers: more expensive, less demand
- Sequence dependent changeovers

Stage 1 transportation

- Either to DC or direct to a warehouse
- Different lot size constraints (truck capacity)
- Problem is known as a Vehicle Routing Problem (VRP)
- Can have resource constraints

Carlsberg supply chain



Stages 2 and 3: Optimization

- Placement of pallets at DC and warehouses
- Transportation to warehouses
- Transportation to customers
  - vehicle routing problem

Scheduling process

- Medium term: 12 weeks
  - given demand and forecasts for products
- 3 MIP models solved sequentially
  - Costs: production, storage (at brewery, DC, warehouse), transportation, tardiness, non-delivery penalty, and violation of safety stock
- Each MIP is composed of 5-10 sub-problems based on products
  - Have 100 000 to 500 000 variables and 50 000 to 150 000 constraints!

Safety stock

- One goal is customer service
  - Usually achieved by maintaining inventory at DC and warehouses
  - Minimum inventory levels = **safety stock**
- A lot of safely stock → good customer service, but also high inventory costs!

Short term scheduling

- Based on medium term schedule, short term scheduling plans the actual production for one week
  - More detailed model of resource (i.e., sequence dependent setup costs)
  - Use genetic algorithm or constraint programming
- Transportation scheduling

Overall process

- Decompositions are crucial
  - medium term/short term
  - product-based
  - transportation scheduling decoupled from production scheduling
- Medium term plan is re-done every day using up-to-date information: **takes 10 to 12 hours**!
- Then short term scheduling is re-done
- See slides of APO-SAP of this example.